Impact of the interfaces for wind and wave modeling - interpretation using COAWST, SAR and point measurements

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Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Larsén, X. G. (Author), Du, J. (Author), Bolanos, R. (Author), Badger, M. (Author), Larsen, S. E. (Author), & Kelly, M. C. (Author). (2017). Impact of the interfaces for wind and wave modeling - interpretation using COAWST, SAR and point measurements. Sound/Visual production (digital)

Impact of interfaces for wind and wave modeling

via coupled atmospheric & ocean wave models, with SAR and mast measurements

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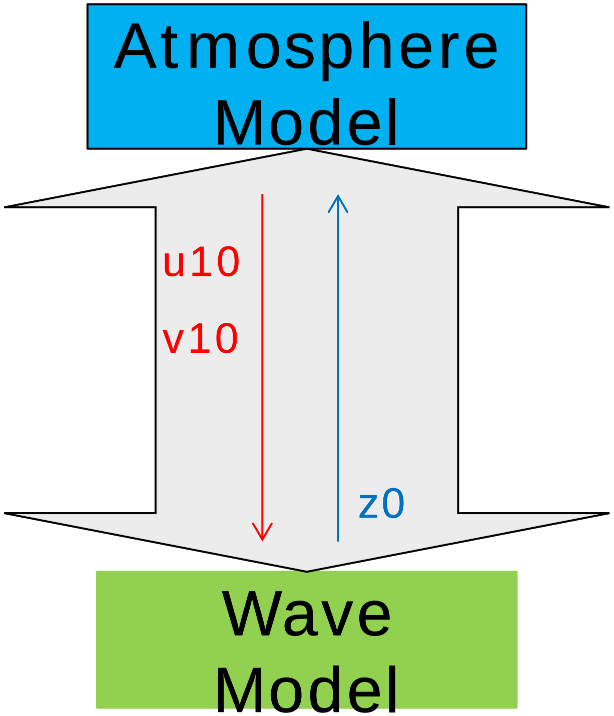
Mark Kelly

Focal point



Method

1. Measurements

2. Development of the Wave Boundary Layer Model (WBLM)

3. Results of application of WBLM

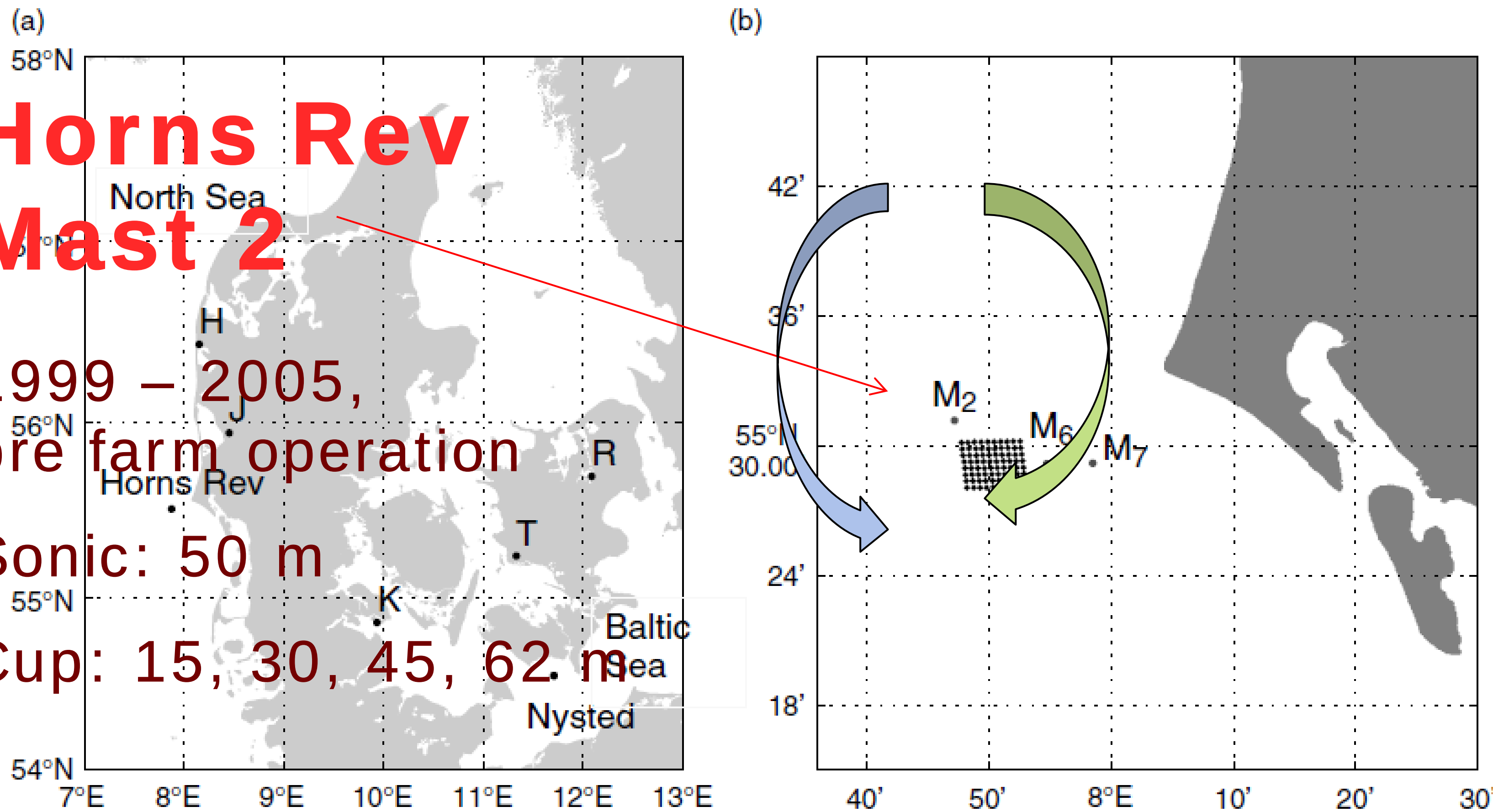
Measurements: from mast & buoy

Horns Rev Mast 2

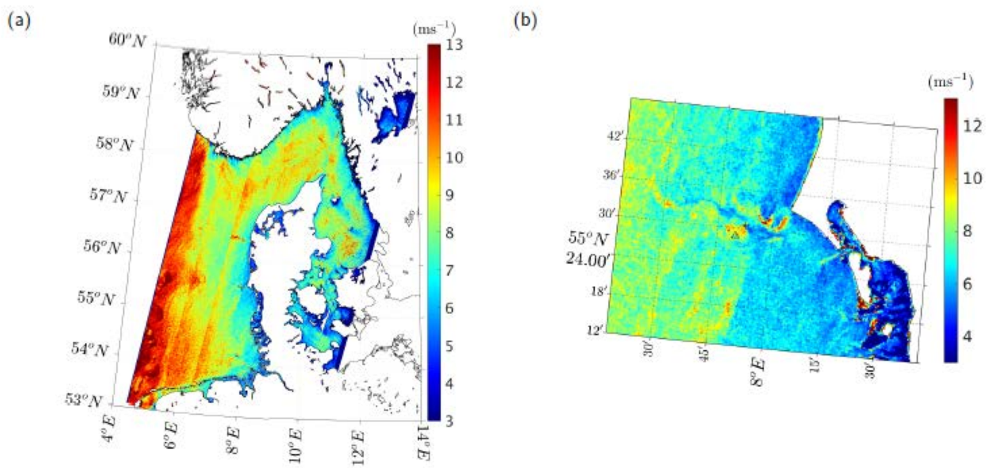
1999 – 2005,
pre farm operation

Sonic: 50 m

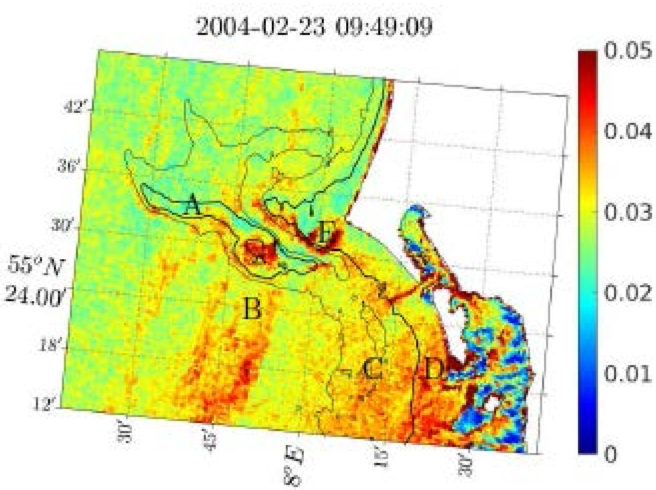
Cup: 15, 30, 45, 62 m



Measurements: ENVISAT Synthetic Aperture Radar

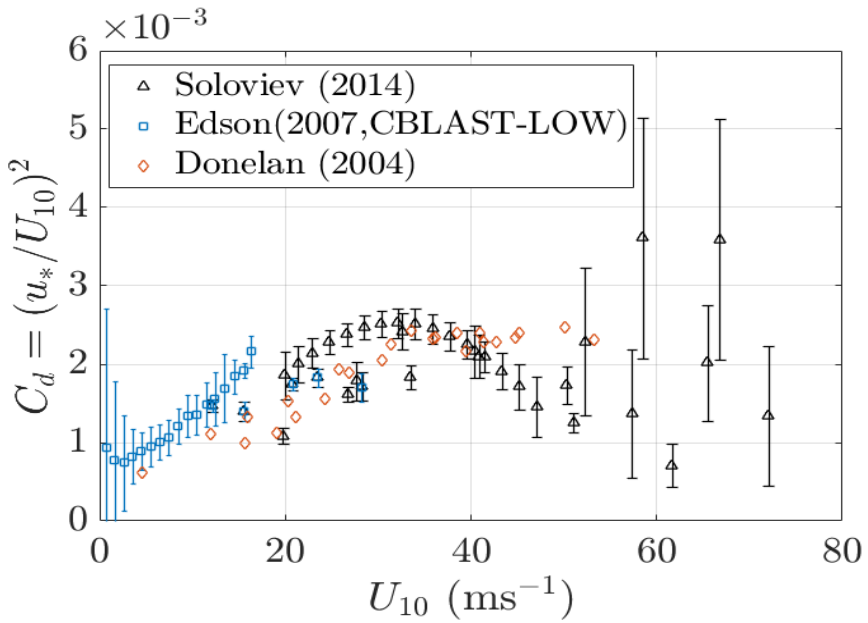


SAR 10 m “wind speed”



Radar backscatter measured by ASAR

Measurements: from literature



Soloviev (2014): A collection of measurements from Powell (2003), Black (2007, CBLAST-Hurricane), Bell (2012), Jarosz (2007), Holthuijsen (2012)

Edson (2007): CBLAST-LOW

Donelan (2004): Laboratory measurements in a wave tank (15m long x 1m wide x 1m high)

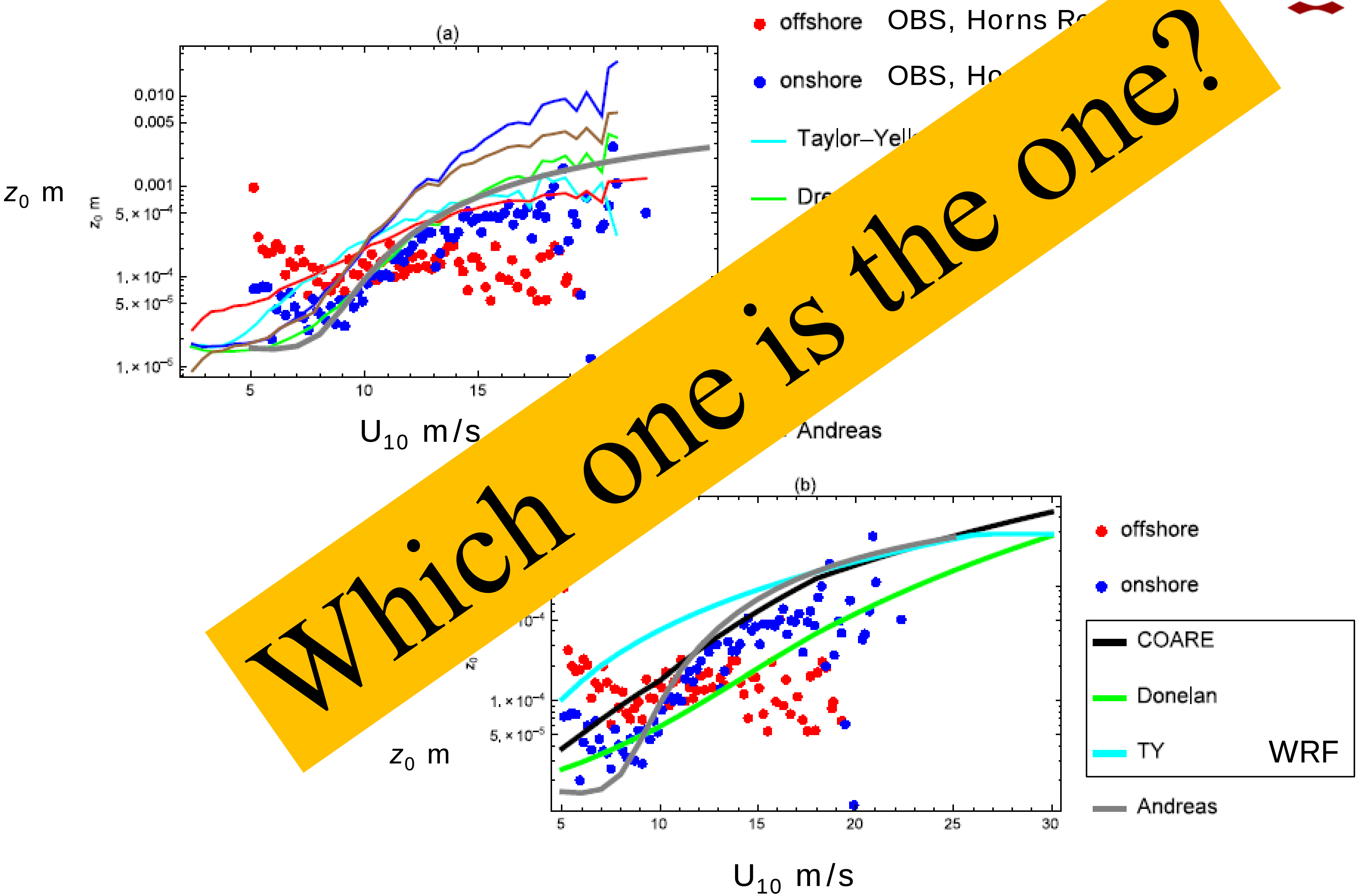
Motivation (1)

Motivation (2)

Schemes	z_0
Charnock	$z_0 = \alpha u_*^2/g$
Drennan et al	$z_0 = 3.35H_s(u_*/c$ …
Fan et al.	$z_0 = \alpha u_*^2/g + 0.11\nu$ … $)^{-b}$ $\quad a = \frac{0.023}{1.0568^{U_{10}}} \quad b = 0.012U_{10}$
Liu et al.	for $0.35 < c$ … … $)^{3/2})^{1-1/\omega}(0.03c_p/u_* \exp(-0.14c_p/u_*))^{1/\omega}$ f … $\alpha = 17.61^{1-1/\omega}0.008^{1/\omega}$ where $\omega = \min(1, a_{cr}/(\kappa u_*))$, with a_{cr} =0.64 ms^{-1}
Oost et al	$z_0 = \frac{50}{2\pi}L_v(\frac{u_*}{c_p})^{4.5} + 0.11\nu/u_*$
SWA	$z_0 = z\exp\left(-u_*/U_{10}\right)$ $u_* = 0.239+0.0433\left((U_{10}-8.271)+\sqrt{0.12(U_{10}-8.271)^2+0.181}\right)$
Taylor-Yelland	$z_0 = 1200H_s(H_s/L_p)^{4.5}$

TOO MANY OPTIONS!

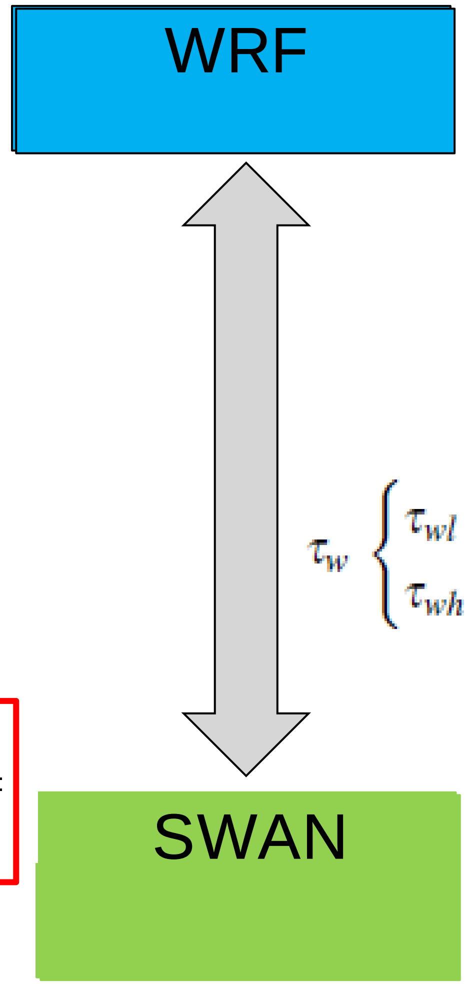
Horns Rev M2



(a)
offshore OBS, Horns R
onshore OBS, Ho
Taylor–Yell
Dr
Andreas
z_0 m
U_{10} m/s
Which one is the one?
(b)
offshore
onshore
COARE
Donelan
TY
WRF
Andreas
z_0 m
U_{10} m/s

Motivation (3)

2



JANSSEN SCHEME

$$u_* = \sqrt{C_d}\,U_{10}$$

$$C_D = \left(\frac{\kappa}{\ln(z/z_0)}\right)^2$$

$$\tau_{tot} = \rho_a u_*^2$$

$$\boxed{z_0 = \frac{0.01 u_*^2}{g\sqrt{1 - \tau_w/\tau_{tot}}}}$$

$$\tau_w \begin{cases} \tau_{wl} = \rho_w \int_{\sigma_{min}}^{\sigma_c} \int_{-\pi}^{\pi} \sigma^2 \beta_g(\sigma,\theta) N(\sigma,\theta)\, d\theta\, d\sigma \\ \tau_{wh} = \rho_w \int_{\sigma_c}^{\sigma_{max}} \int_{-\pi}^{\pi} \sigma^2 \beta_g(\sigma,\theta) N(\sigma_c,\theta) \left(\frac{\sigma_c}{\sigma}\right)^6 d\theta\, d\sigma \end{cases}$$

with

$$\beta_g(\sigma,\theta) = C_\beta \sigma \frac{\rho_a}{\rho_w}\left(\frac{u_*}{c}\right)^2 cos^2(\theta - \theta_w)$$

$$\begin{cases} C_\beta = \frac{J}{\kappa^2}\lambda \ln^4 \lambda, & \lambda \le 1 \\ \lambda = \frac{g z_0}{c} \exp\left(\kappa c / \left|u_* \cos(\theta - \theta_w)\right|\right) \end{cases}$$

The Wave Boundary Layer Model

Conservation of momentum :

$$\vec{\tau}_{tot}(z) = \boxed{\vec{\tau}_t(z)} + \vec{\tau}_w(z) = constant \qquad \vec{\tau}_w(z) = \rho_w \int_{\sigma_{min}}^{\sigma_z} \int_{-\pi}^{\pi} \beta_g(\sigma,\theta)\,\sigma^2 N(\sigma,\theta)\,\frac{\vec{k}}{k}\,d\theta d\sigma$$

$$\beta_g(\sigma,\theta) = C_\beta \sigma \frac{\rho_a}{\rho_w}\left(\frac{\boxed{u_*^l}}{c}\right)^2 cos^2(\theta-\theta_w)$$

--Wave growth is proportional to the local turbulent stress

Conservation of kinetic energy:

$$\frac{d}{dz}(\vec{u}\cdot\vec{\tau}_{tot}) + \boxed{\frac{d\Pi}{dz}} + \frac{d\Pi'}{dz} - \rho_a\varepsilon = 0$$

Wave-induced energy flux

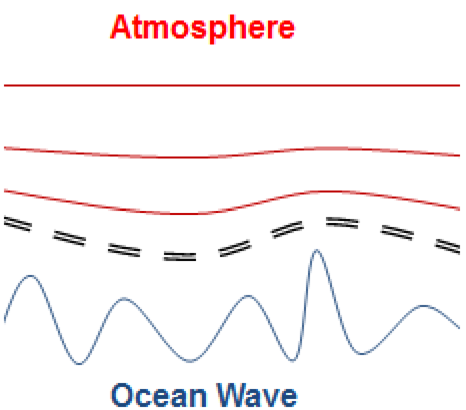
$$\Pi(z) = \int_{\sigma_{min}}^{\sigma} \tilde{F}_w(\sigma)\,d\sigma \qquad \tilde{F}_w(\sigma) = \rho_w \int_{-\pi}^{\pi} \beta_g(\sigma,\theta)\,g\sigma N(\sigma,\theta)\,d\theta$$

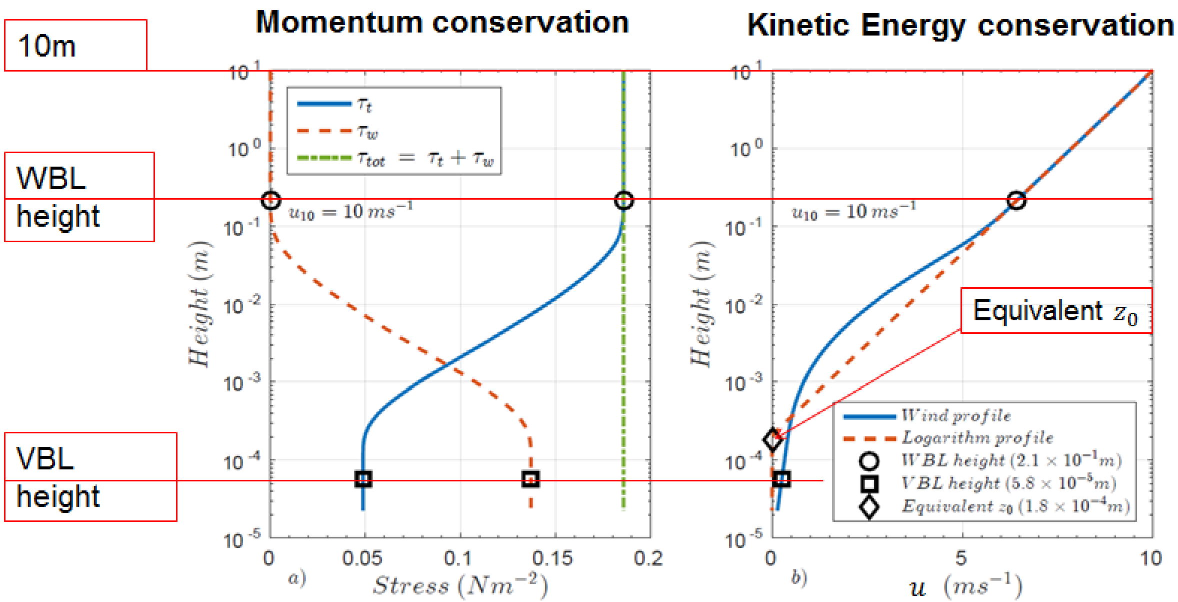
$$\frac{d\vec{u}}{dz} = \left[\frac{\delta}{z^2}\tilde{F}_w\left(\sigma = \sqrt{g\delta/z}\right) + \frac{\rho_a}{\kappa z}\left|\frac{\boxed{\vec{\tau}_t(z)}}{\rho_a}\right|^{\frac{3}{2}}\right] \times \frac{\vec{\tau}_t(z)}{\vec{\tau}_t(z)\cdot\vec{\tau}_{tot}}$$

--Wind profile in the wave boundary layer

The Wave Boundary Layer Model

WRF

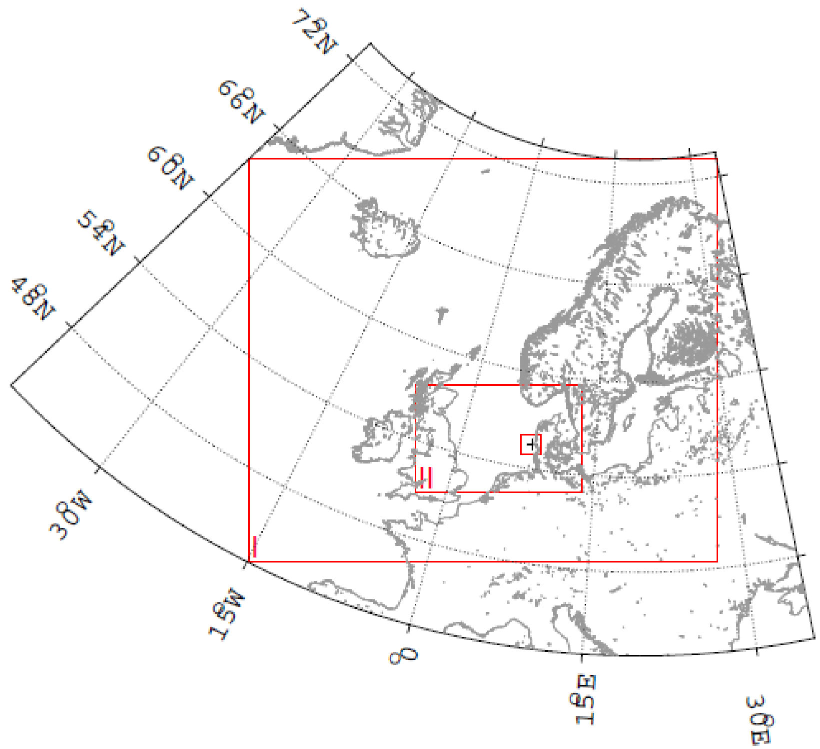




Du, J., Bolaños, R., and Larsén, X. (2017a). The use of a wave boundary layer model in SWAN. *Journal of Geophysical Research: Oceans*, pages 1063–1084.

SWAN

Model setup



Two-way online
Nested 9-3-0.6km
30 hours for each run

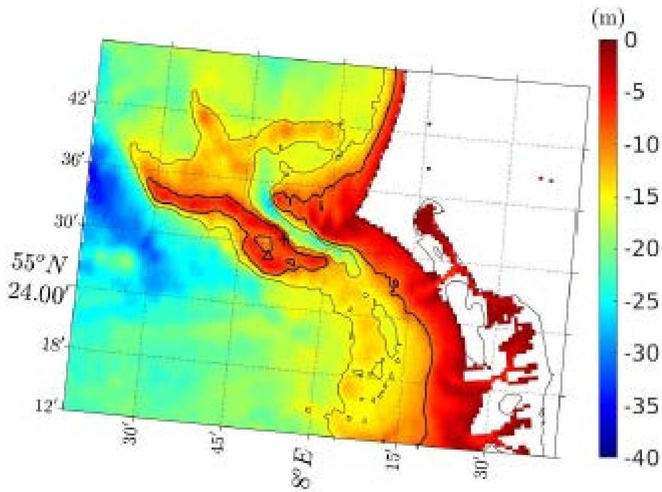
WRF:
CFSR+OISST
77 vertical sigma levels
MYNN 3.0 PBL scheme
RRTM long and short wave radiation
Kain-Fritsch cumulus scheme (domain I)
Corine land use

SWAN:
1/8 arc-minute bathymetry data
Initiated 24h before the simulation
Close boundary for open sea
36 directional bins.
0.03 Hz < f < 10.05 Hz (KOM and WBLM)
0.03 Hz < f < 0.57 Hz (JANS)

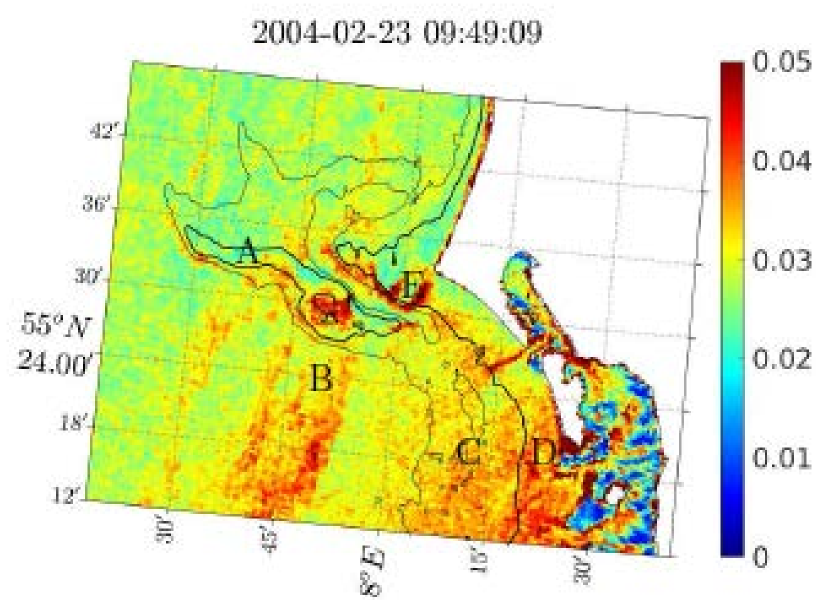
Model performance

Cases are chosen to emphasize the conditions: storm and/or coastal

Example case 1: 2004-02-22 – 2004-02-24 (coastal, moderate to strong wind)



bathymetry



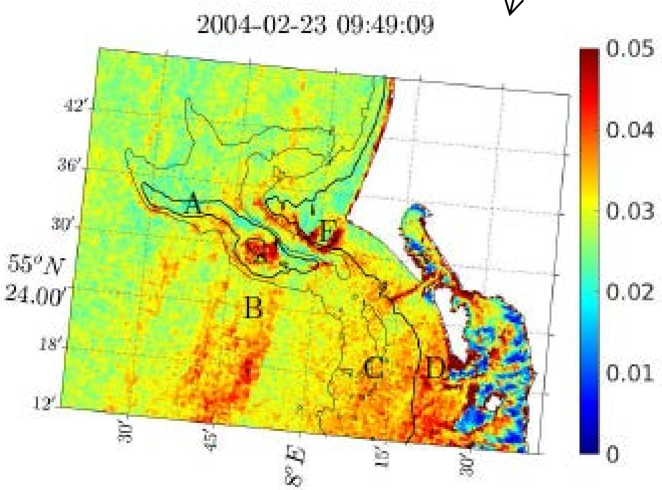
Radar backscatter measured by ASAR

Model performance

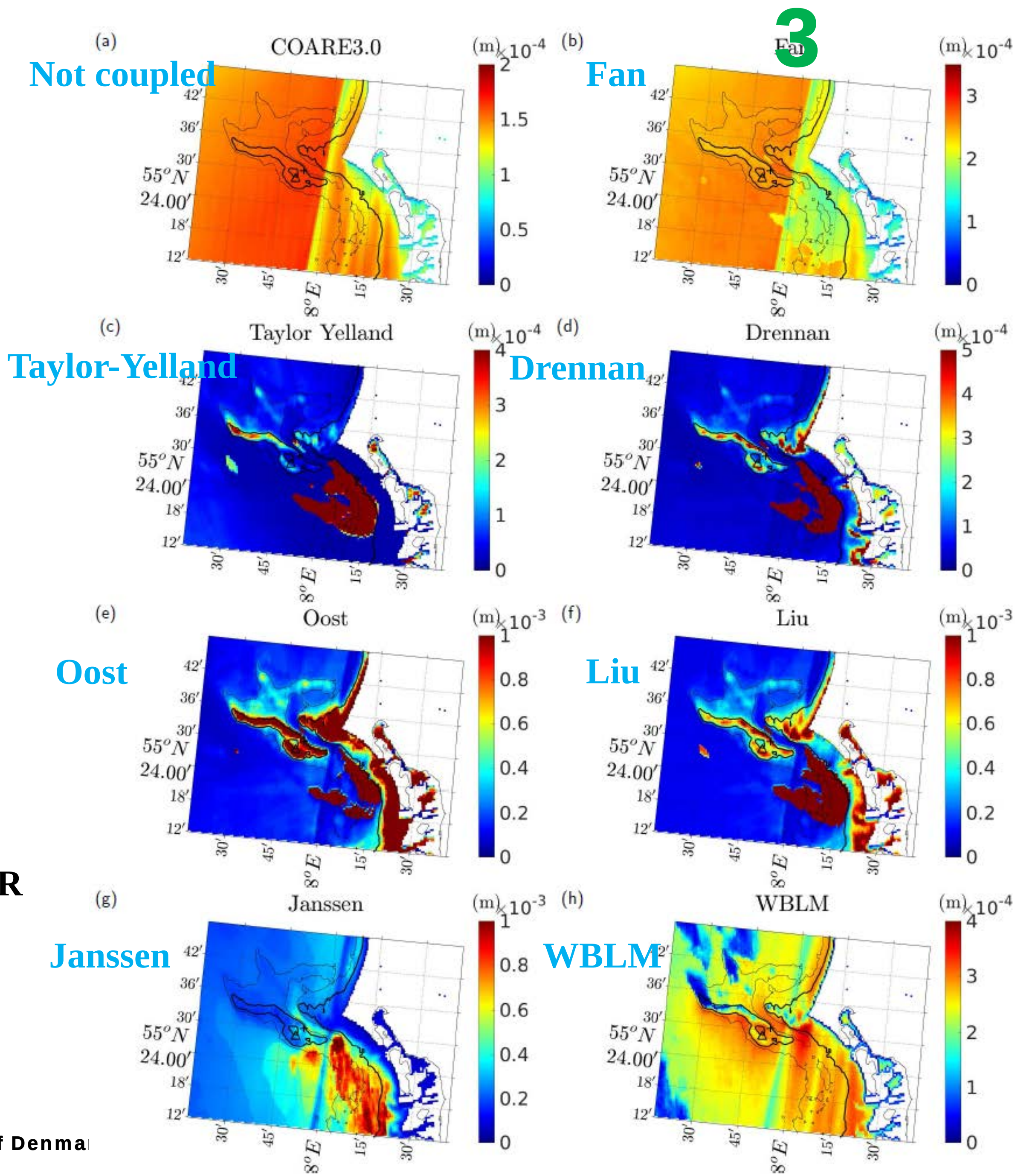
Roughness length

2004-02-23 09:50

Wind vector



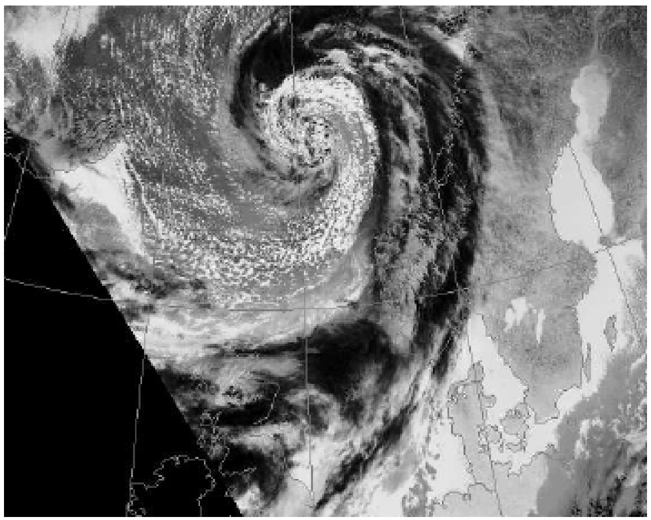
Radar backscatter measured by ASAR



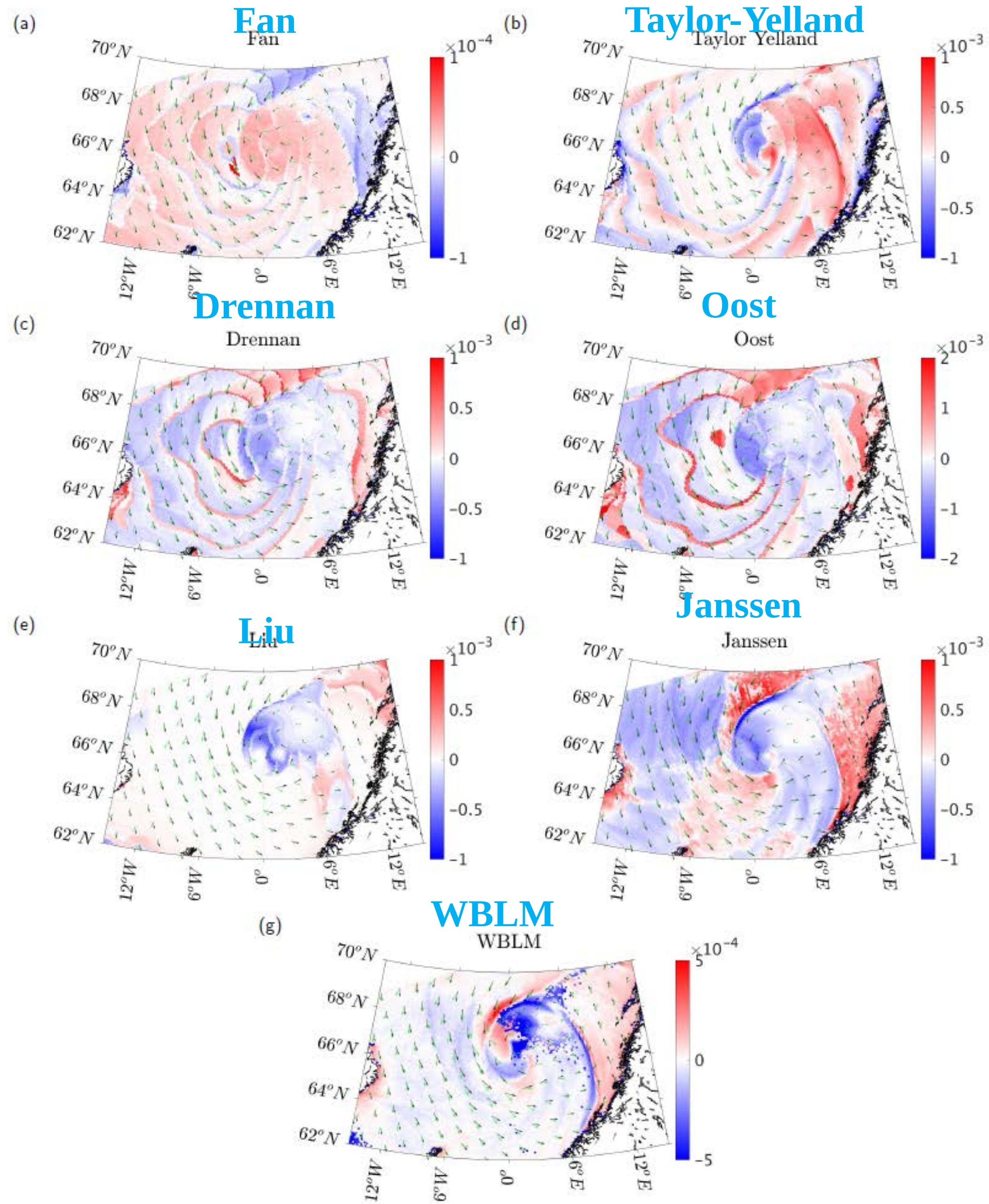
Model performance

Drag coefficient difference:

coupled - uncoupled



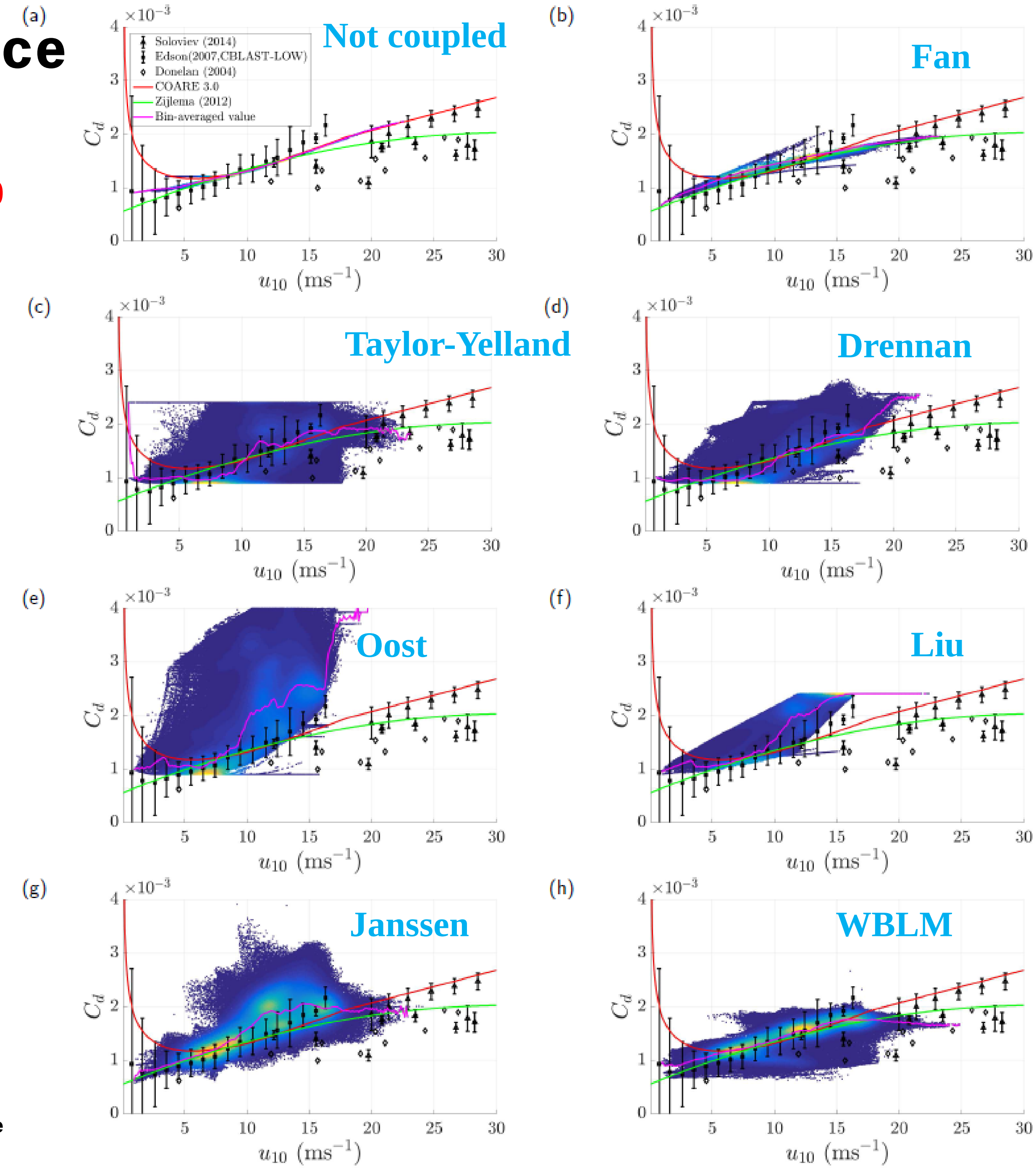
20:45, 2004-02-23



Model performance

Drag coefficient *vs.* U_{10}

Whole domain III, entire period



Model performance

$\Delta U_{10}/U_{10}$ (%)

Between coupled and not-coupled

20:45, 2004-02-23

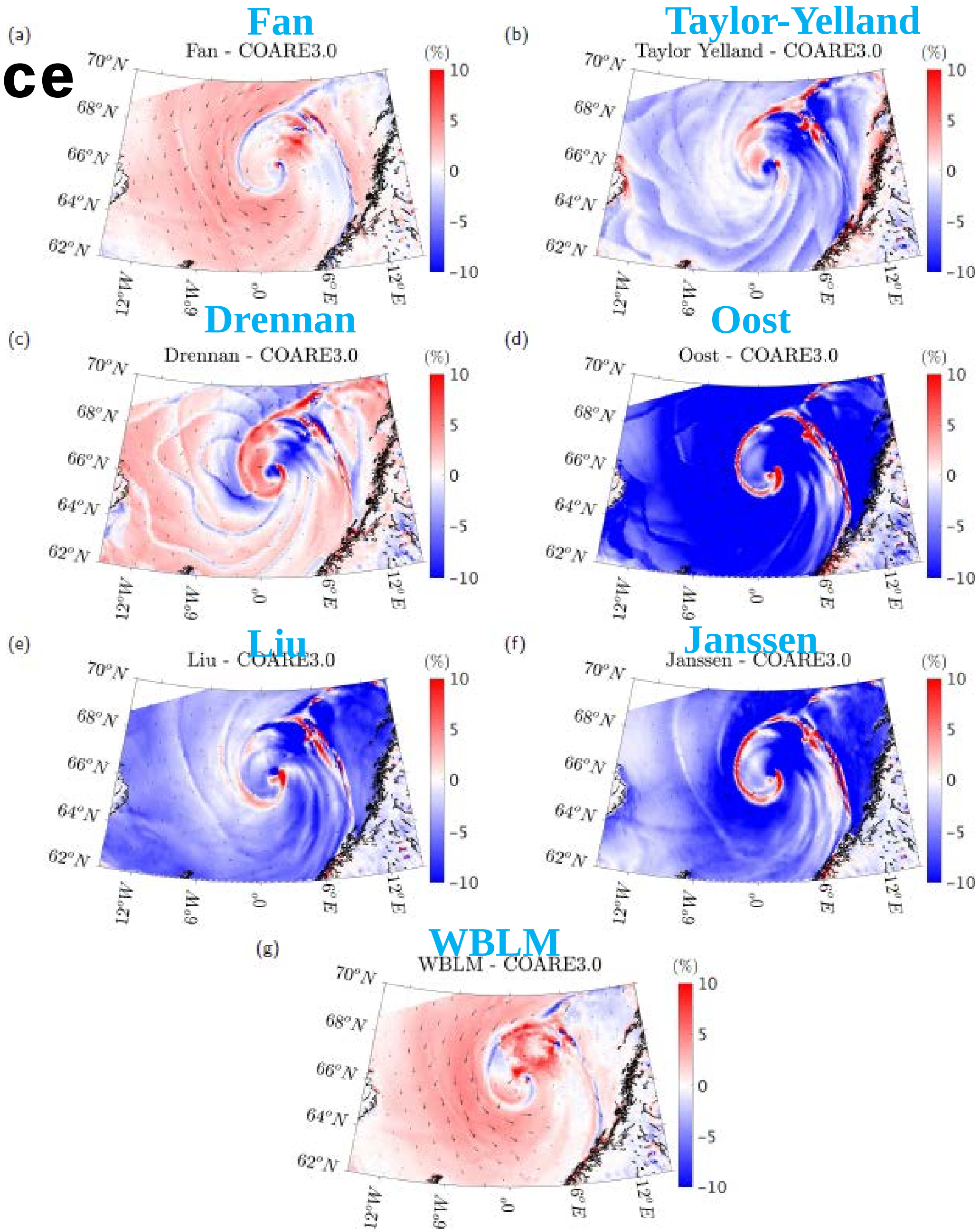


Figure 8.13: Percentage of deviation in U_{10} between the coupled and non-coupled modeling at the same time as Figure 8.12.)

Discussion and summary

- Coastal wind-wave relations are more complicated than for open sea conditions
- Existing modeling approaches are of limited use during storm conditions
- Tests of z0 -parameterizations to couple atmospheric models and wave models are inconclusive
- A Wave Boundary Layer Model (WBLM) is implemented in SWAN, using conservations of momentum and turbulence kinetic energy to be coupled to WRF
- WBLM outperforms the other schemes in coastal and stormy conditions

Thanks to the support

- Project: Danish PSO 12020 X-WiWa
- Project: EU CEASELESS
- Horns Rev data from DONG Energy
- SAR data from European Space Agency
- Open source WRF, SWAN, COAWST